Integration of Archive Data for River Quality Assessment

F.J.Simpson, D.J.Balmforth**, J.Blanksby***, R.J.Gadsden***, D.Stewart**
**   Environment Agency, ** Montgomery Watson, *** Sheffield Hallam University*

Synopsis

The paper looks at the current chemical sampling programme and analysis procedures for river water quality. It investigates how the integration of flow data with the current chemical sampling may provide an enhanced assessment of river quality.

Introduction

The current chemical criteria of assessment for river water quality are based on percentiles set out in Water Quality Objectives: Procedures used by the National Rivers Authority for the purpose of the Surface Waters (River Ecosystem) (Classification) Regulation 1994 and the General Quality Assessment (GQA). The GQA assessment also includes other windows on water quality including biology, nutrients and aesthetics. In an ideal world, the different forms of sampling would paint a consistent picture of river quality. In particular, it would be expected that chemical and biological measures would produce similar results. However this is not always the case, especially where the river flows through urban areas affected by intermittent discharges. Table 1 shows the discrepancies that may occur between the chemical and biological classification of an urban Blackburn Brook in Sheffield, in contrast to the rural Kirkby Beck near Malham.

River	Biological Grade		Chemical Grade	
	1990	1995	1990	1995
Kirkby				
(rural reach)	b	a	B	B
Blackburn				
(urban reach)	-	e	C	B

Table 1: Comparison of urban and rural stream quality grades.

This problem is not confined to the Blackburn Brook. In the North East region it is generally the case. Table 2 shows the type of discrepancies that occur in the North East region for the 1990 and 1995 surveys (Data are omitted where sample sites have been relocated).

	Biological		Chemical		No
	1990	1995	1990	1995	
Change and Grade matched	e	C	E	C	7
Consistent Change (mismatched Grade)	c	C	B	B	11
Grade and Change mismatche	c	C	E	B	63
n.b. Gradings shown are illustrative.					

Table 2: Data consistency comparison between chemical and biological grades.

Although the schemes are not directly compatible, the variations and conflicting results provide little indication of real improvements in river quality. Indeed, today, where water companies are being judged on improvements in river quality, discrepancies between assessments can lead to confusion.

In addition to the prescribed sampling programmes, the Environment Agency archives continuous (15-minute) flow data from permanent river gauging stations positioned within the river network. Besides flood defense and other associated work the data is utilized together with water quality data in mass balance calculations to set the consents for sewage treatment works discharges (Figure 1). However it is not currently used to complement the GQA data in the assessment of river quality.

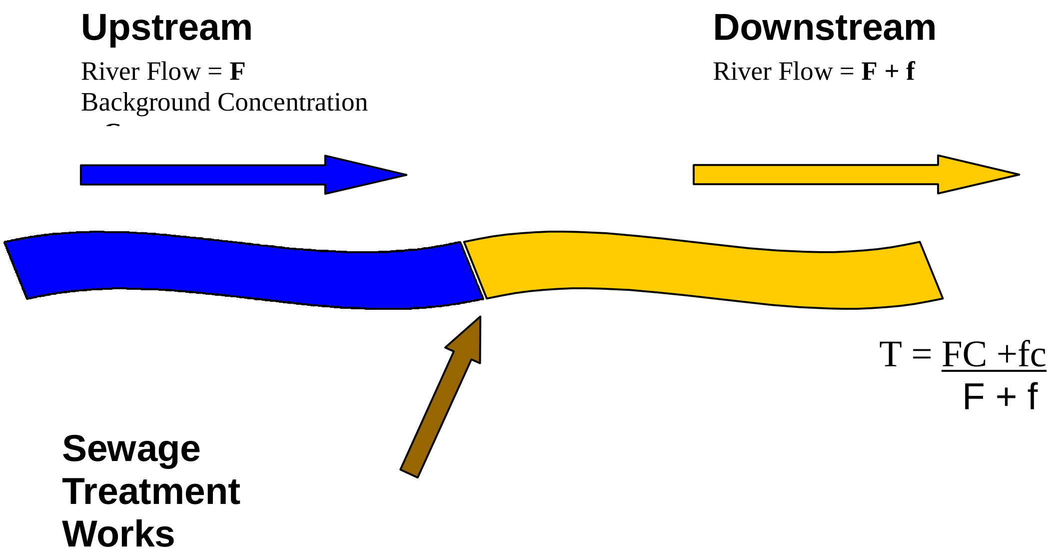

Figure 1: Mass-balance calculation of downstream pollutant concentration.

The use of the mass balance calculation to determine consents employs the use of summary statistics for both the chemical and river flow data, along with those of the flow and quality of the discharge. Statistical techniques using combined distributions are then be applied to obtain a consent standard for the discharge to ensure the downstream river quality objectives are met.

Pollution sources affecting river systems may be classified in two ways: point and non-point, continuous and intermittent. The relationship between these is shown in Figure 2

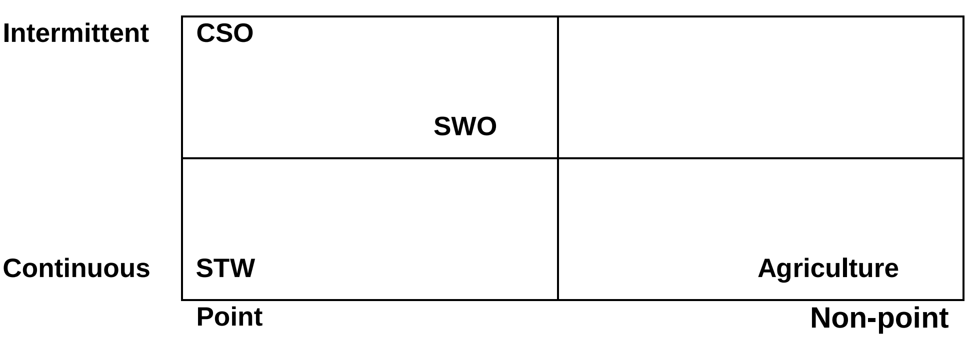

Figure 2: Relationship between point and non-point discharges.

From a wastewater industry perspective, continuous discharges are predominantly related to sewage treatment works, however contaminated surface water outfalls may locally occur. Intermittent discharges are predominantly combined sewer overflow and surface water outfalls operating in wet weather, however, quasi random pumping station failures and in-system blockages also occur and are occasionally sampled. From this basis, it is possible to associate continuous discharges with dry weather flow and intermittent discharges with wet weather flow

There are other sources of discharges from other industries, including agriculture and from natural sources.

By using percentiles to express river quality, the chemical sampling combines the effects of continuous and intermittent (dry and wet weather) discharges and fails to discriminate between point and non-point sources of pollution.

The wastewater industry has and continues to invest large sums of stakeholders' money in making improvements to discharges from sewage treatment works and combined sewer overflows. In the future, it is probable that money will also be directed at surface water outfalls. Although the current sampling may identify an improvement in quality, it is not able to identify and quantify the reason for the improvement or to contribute information to help in the identification of problems or the design of solutions.

Benefits of differentiating between dry and wet weather flows

By associating the chemical samples with the flow conditions at river gauging stations, it is possible to identify if samples were taken during dry or wet weather. This has a number of benefits:

The general quality of the river in dry weather can be established

Figures 3 shows two distributions for BOD samples taken on the Silk stream in North London. The distributions represent samples taken during wet and dry weather periods. The stream can be seen to be the subject of poor water quality during dry weather, and poorer quality during wet weather. The stream is not subject to continuous sewage treatment work discharges but has a chronic CSO problem.

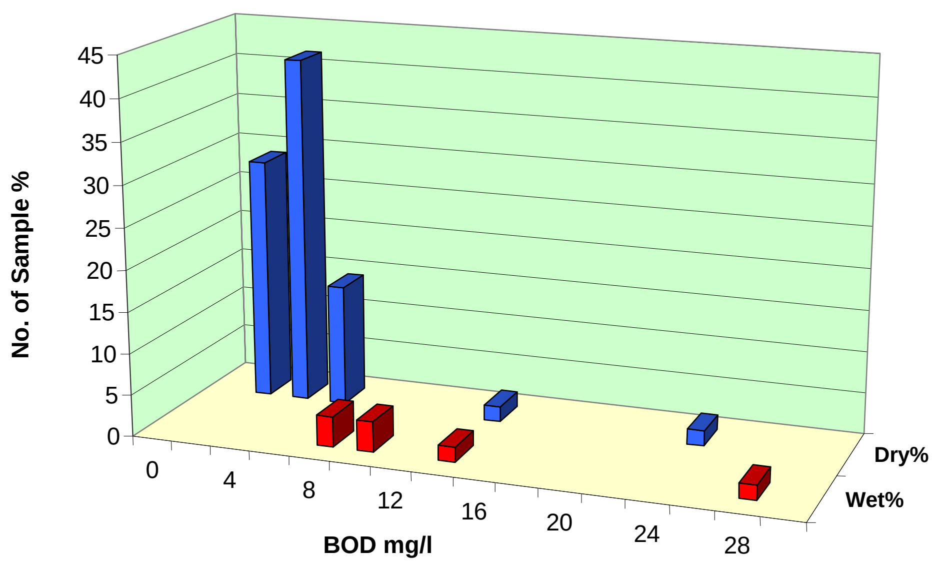

Figure 3: Silk Stream Wet and Dry Sample Distributions 1994 -1998

The shift that is event evident in the quality of the wet weather samples does indicate that the cause of the severe pollution is weather dependent. In addition, the apparent outliers in the dry events may indicate misconnections to the surface water system that should also be investigated.

Figure 4 indicates the flashiness of the catchment, which is heavily urbanized. The peaks shown in figure 4 are typical for the 5-year period considered. Due to the random sampling strategy employed in the chemical monitoring programme, the chance of sampling such events is low. The greatest flow rate sampled for the 5 year period was 0.454m3/s, however numerous events occur in each year that exceed this threshold.

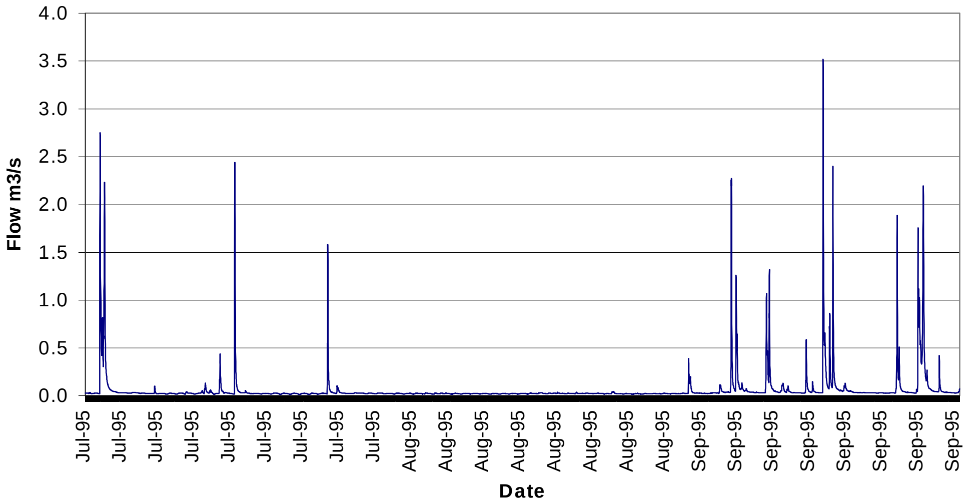

Figure 4: Silk Stream hydrograph July – September 1995

The rate of change in the flow is an important factor, as this provides an indication of how the event Hydrograph has been generated. Runoff generated in urban areas produces greater rates of change in the Hydrograph and reduces the time to peak in the Hydrograph. Balmforth et al identified that intermittent discharges can be identified by the shape of Hydrograph produced. For the period of 1995, rates of change in flow (15-minute period) were observed between 0 – 3.584 m3/s however, greater rates of change were observed for other events during the 5-year period. As higher rates of change in flow may be related to the characteristics of intermittent discharges from urban areas it is important they are sampled, particularly as their pollution has a disproportionate effect on the river water quality (Urban Pollution Management Manual).

Figure 5 show the total 1995 rates of change in flow distribution, and the distribution of those rates of change in flow that were sampled. As the chemical sampling is random, it reflects the higher frequency (small) rates of change in 1995, as expected. However, it is the higher rates of change, associated with wet weather and the higher pollution loads in the river. As the higher rates of change in flow rate remain unsampled, those that may be associated with CSO discharges, the assessment of their impact may remain undetected.

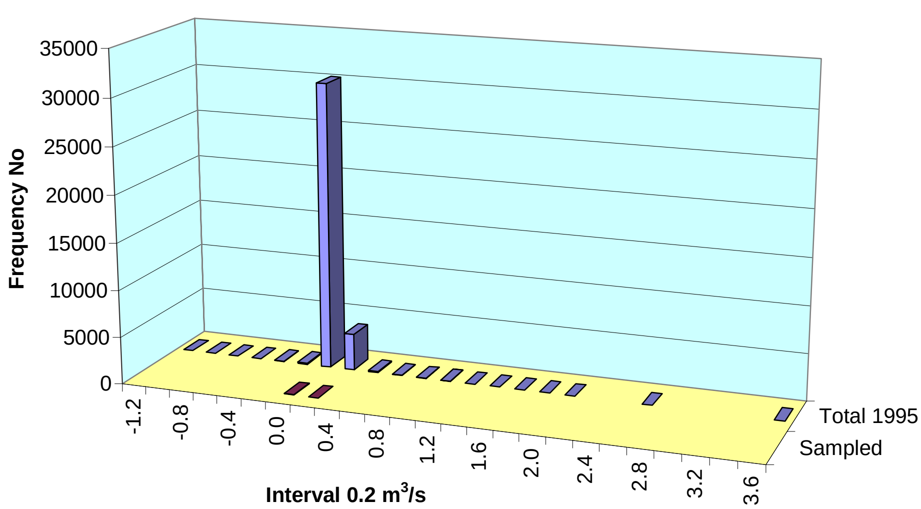

Figure 5: Frequency distribution of rates of change in river flow for the Silk Stream 1995

The distributions shown in Figure 5 indicate that the events likely to contain the poorest river quality and those likely to contain CSO discharges remain undetected by the current sampling scheme. It should be noted that the highest rate of change sampled for the entire 5 year data set was –0.101 m3/s (falling limb).

The effect of improvements to continuous discharges can be quickly established

Where rivers are subjected to a continuous discharge like those associated with sewage treatment works their impact on the receiving waters may be easily identified. Figure 6 illustrates the wet and dry weather distributions of phosphate in the River Ray downstream of Swindon STW for two periods (1991-98 and 1999). The river above the sampling point is known not to be subject to intermittent discharges from CSOs. However there are surface water outfalls.

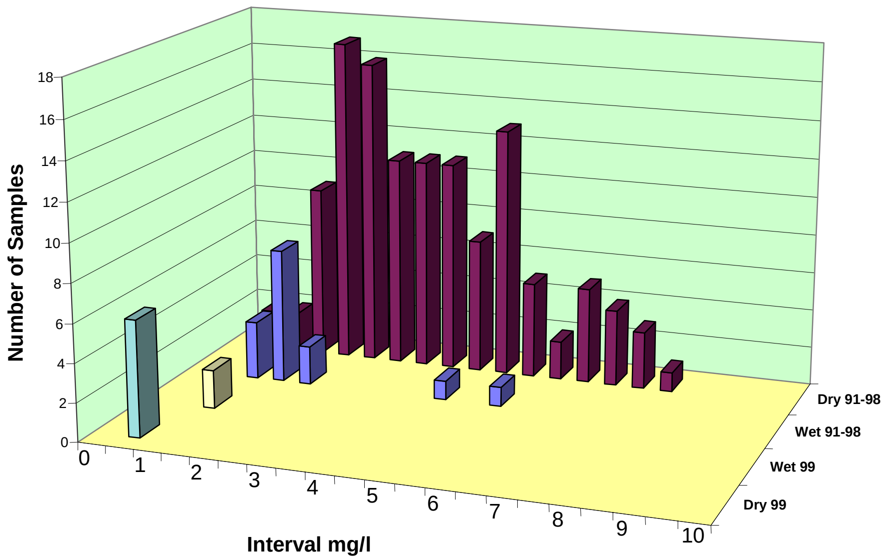

Figure 6: Phosphate removal at Swindon STW Impact on River Ray water quality

During dry weather periods, the discharge from the STW accounts for approximately 70% of the DWF of the river. The wet and dry distributions for the period from 1991-1998 shows that during dry weather the river water quality is adversely effected by the STW discharge. However, during wet weather the additional flow dilutes the impact of the phosphate from the STW resulting in an improved quality. During 1998, phosphate removal was installed at the works and the distributions for wet and dry weather clearly indicate the improvement in river quality. The distribution for the wet weather flow during 1999 confirms that there is not a problem associated with phosphate during wet weather events.

Consideration can be given to long term flow conditions and the effects of intermittent discharges during this period

Figure 7 provides a comparison of flow in the Blackfoss Beck and River Sheaf. Both catchments are of similar Area approximately 49 km2. The Blackfoss Beck is mainly a rural catchment whereas the Sheaf is heavily urbanised and subject to intermittent discharges. Although the catchments are separated geographically they both lie in the North and experience similar rainfall. From Figure 7 it is possible to see that during winter wet weather similar hydrographs patterns are present, however during the summer months there is only a low response to rainfall in the Blackfoss due to high infiltration. Although the upper reaches of the Sheaf are open moorland, during the summer months Hydrograph shapes emerge that are related to intermittent discharges from the high urban fraction. The important issue here for river water quality is not only the intensity of rainfall causing the events but the antecedent dry period before the event. As the baseflow reduces during dry weather a rainfall event with a high frequency can have a more significant effect on the river quality than a high intensity rainfall event preceded by wet weather. This is due to dilution achieved in the river at the time the events occur.

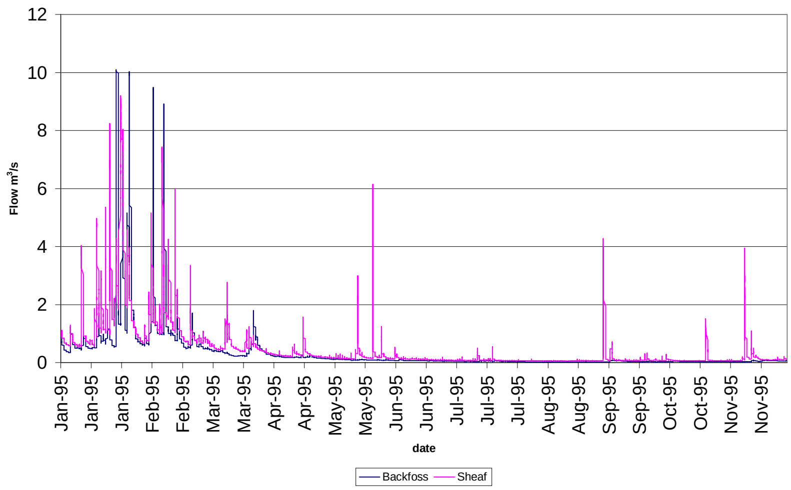

Figure 7: Blackfoss Beck and River Sheaf 15 minute flow data 1995

Examination of continuous flow data in this way can reveal the return period of rainfall and dry antecedent period that creates the true critical water quality in the river itself. This type of approach is river orientated and represents the actual conditions experienced in the catchment. It also suggests that sustainable urban drainage systems, which increase river base flows and reduce discharge from urban drainage systems through infiltration are appropriate long term solutions to pollution which should be pursued.

The impact of intermittent discharges and re-entrainment of bed load can be established, including the effect of antecedent dry periods.

During times of low intensity rainfall over longer periods, the impact of intermittent discharges becomes more masked particularly in mixed catchments where the runoff from the rural fraction becomes more significant. The impact on the receiving waters is also reduced as greater dilution is normally achieved. Figure 8 shows a comparison between the Blackfoss and Sheaf for a winter rainfall event, which are normally associated with lower intensity and longer duration rainfall than summer storms. However the characteristic fast response of the urban fraction is still visible, but may not have as significant an impact on the receiving waters due to the higher baseflow than a summer storm. In Figure 8 the response from the River Sheaf rural fraction can be seen lagged behind that of the urban fraction, this is nearly matched by that of the Blackfoss in recession.

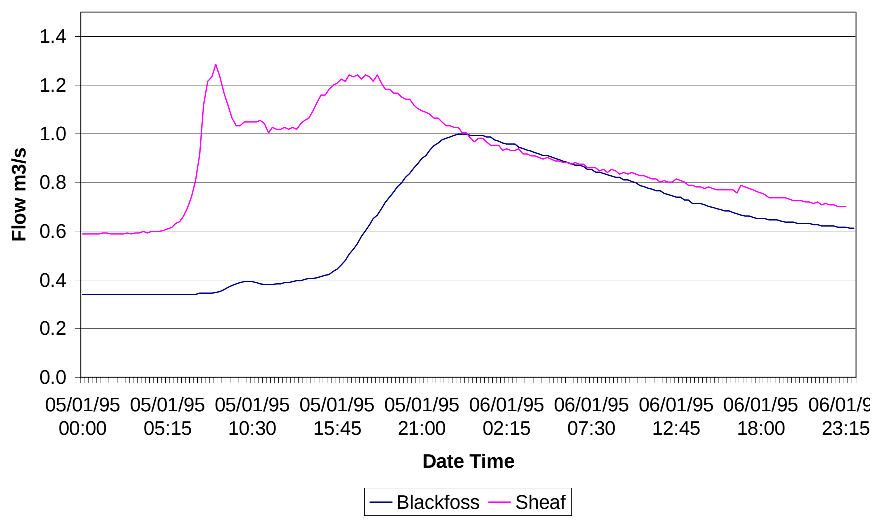

Figure 8: Comparison of Blackfoss Beck and River Sheaf winter event

In contrast to the winter event, Figure 9 illustrates how the dry antecedent period can have a major impact on the dilution of any intermittent discharge. The period of dry weather is reflected by the low baseflow in the both rivers. However, due to the rapid runoff of the urban fraction in the Sheaf catchment little dilution is achieved to the intermittent discharge. The rates of change in flow are characteristic of intermittent discharges with peaks of 2.5 – 4 m3/s and return to near baseflow being achieved within 1-2 hours. Where, in the Blackfoss catchment there is little response to the event. The visual and fundamental difference between the two catchments in their response to rainfall is made possible only with the use of the continuous flow (15 minute) data.

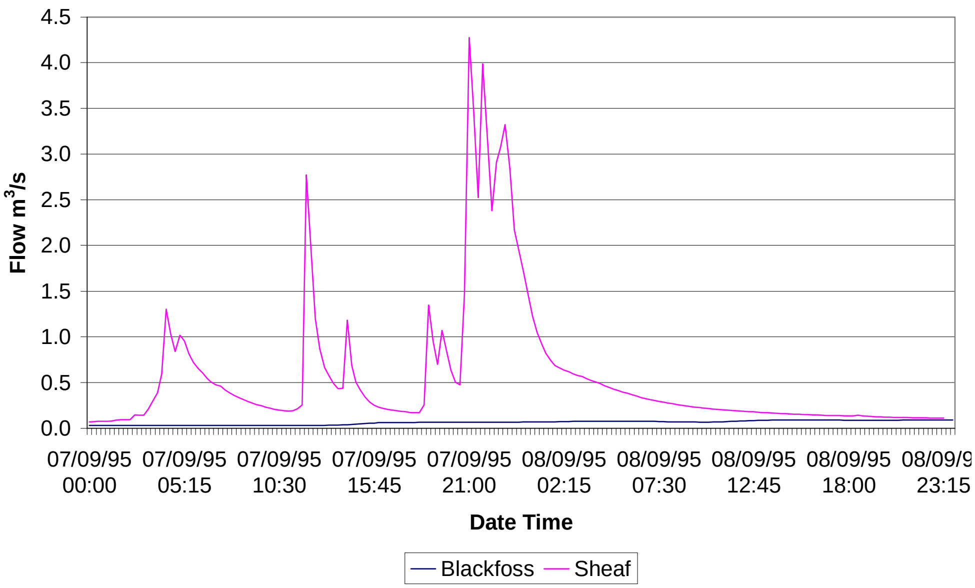

Figure 9: Comparison of Blackfoss Beck and River Sheaf summer event

Data of this type may allow the use of shape recognition techniques to recognise the frequency of intermittent discharges within a catchment. Research at Sheffield Hallam University has already had success using shape recognition techniques to identify and catagorise synthetic river flow hydrographs by type i.e. hydrographs subjected to intermittent discharges and those which are not.

Study Programme

A study programme investigating a number of issues arising is being developed.

The first stage has been to develop tools that will assist in analysing data from the databases containing the chemical sampling and river gauging data. The issue here is not just to recognise wet weather flows, but to identify those flows affected by intermittent discharges and if possible to differentiate between combined sewer overflow and surface water outfall discharges. By using multi variate statistical analysis techniques, including neural networks, it has been demonstrated that this is possible for modelled outputs using design and long series rainfall.

The next stage is to confirm the applicability of the shape recognition tools on a sufficiently large population of recorded data and at the same time confirm the benefits of the currently identified uses of the data.

The final stages are to investigate additional benefits that are currently at the stage of hypothesis. These include:

- The establishment of a relationship between pollutant concentration and the rate of change of flow and the river base flow.
- Identify and quantify the effects of CSO improvements and subsequently develop a river centred model for predicting the effects of CSO enhancements.
- The identification of residual non-point source pollution and hence the limitations of quality enhancements that can be achieved by improving STW and reducing CSO discharges.

Conclusions

The separation of dry and wet weather flow samples for analytical purposes provides a vehicle for demonstrating improvements to receiving water resulting from expenditure on sewage treatment works and CSO's.

The current sampling programme provides a high degree of confidence in the dry weather sampling (i.e. the measurement of the effects of continuous discharges)

The small number of wet weather samples causes a problem in demonstrating the effects of intermittent discharges. However the development of the tools in the study programme coupled with the understanding of river processes developed during the research for the UPM may prove to be sufficient for this purpose

Other options for wet weather sampling would be to carry out medium term river sampling studies, or to divert resources from dry weather sampling to wet weather sampling. However both of these have cost/organisational implications on the Environment Agency and can only be considered once the benefits of the study programme can be fully demonstrated.

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Discussion

Martin Osborne **BGP Reid Crowther**

Why use BOD as a parameter?

Answer

Could us any of the determinants, just used BOD as an example.